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Respiratory Muscle Training in Patients With Mechanical Ventilation: A Narrative Review

Entrenamiento de músculos respiratorios en pacientes con ventilación mecánica: una revisión narrativa

Roberts, Bruno[1]; Provitina, María Paz[1]; Rudi Verónica[1]; Saibene, Valentina[1]

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Correspondence
Bruno Roberts. E-mail: klgorobertsbruno@gmail.com

ABSTRACT

Background: Prolonged weaning, characterized by a delayed separation from mechanical ventilation, is associated with significant complications and high mortality rates. Diaphragmatic weakness emerges as a common cause of weaning failure, affecting a large percentage of patients. In response to this challenge, respiratory muscle training presents a promising strategy.

Objective: To present the available evidence on the implementation of respiratory muscle training in patients undergoing mechanical ventilation and its impact on various clinical variables.

Material and Methods: A literature search was conducted for articles published up to December 2023 using various MeSH (Medical Subject Headings) terms and keywords. After applying filters, 25 articles were selected. The search was completed manually by reviewing the reference lists of the selected articles.

Development: Approaches vary between strength training programs and resistance training methods. All of them impact mechanical ventilation weaning time, maximal inspiratory strength, and quality of life as assessed by questionnaires such as EQ-5D and SF-36.

Conclusions: Despite the variability of studies regarding training methods and the optimal load, respiratory muscle training in adult patients under mechanical ventilation can result in improved respiratory muscle strength, reduce the duration of mechanical ventilation in specific patients, and improve quality of life.

Key words: Artificial respirator; Respiratory muscles; Respiratory muscle training; Mechanical ventilation; Weaning, intensive care

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[1]Kinesiology Service, Hospital Interzonal General de Agudos General San Martín de La Plata (Buenos Aires, Argentina)

RESUMEN

Introducción: El destete prolongado, caracterizado por una separación tardía de la ventilación mecánica, conlleva significativas complicaciones y una alta mortalidad. La debilidad diafragmática emerge como una causa común de fracaso en el destete, afectando a un gran porcentaje de pacientes. Frente a este desafío, el entrenamiento de los músculos respiratorios se presenta como una estrategia prometedora.
Objetivo: Exponer la evidencia disponible sobre la implementación del entrenamiento de los músculos respiratorios en los pacientes bajo ventilación mecánica y el impacto en diversas variables clínicas.
Materiales y Métodos: Se realizó una búsqueda bibliográfica de artículos publicados hasta diciembre de 2023 con diversos términos MeSH y palabras claves combinadas. Se seleccionaron 25 artículos posterior a la colocación de filtros. La búsqueda se completó manualmente con la revisión de referencias bibliográficas de los artículos seleccionados.
Desarrollo: Los enfoques varían entre programas de entrenamiento de fuerza y métodos de entrenamiento de resistencia. Todos estos impactan sobre el tiempo de destete de la ventilación mecánica, fuerza inspiratoria máxima y calidad de vida evaluada mediante cuestionarios como EQ5D y SF-36.
Conclusiones: A pesar de la variabilidad de los estudios en cuanto a los métodos de entrenamiento y cuál es la carga óptima, el entrenamiento de los músculos respiratorios en pacientes adultos bajo ventilación mecánica puede resultar en una mejoría de la fuerza de los músculos respiratorios, reducir la duración de la ventilación mecánica en pacientes específicos y mejorar la calidad de vida.

Palabras claves: Respirador artificial; Músculos respiratorios; Entrenamiento de músculos respiratorios; Ventilación mecánica; Destete, Cuidados intensivos

INTRODUCTION

Weaning is the process of liberating a patient from mechanical ventilation (MV) and begins with the first attempt to separate them from it, whether through a spontaneous breathing trial (SBT) in any of its modalities or through extubation without SBT in patients under orotracheal intubation (OTI). For tracheostomized patients, it starts after completing at least 24 hours without requiring MV.[1,2]

Weaning can be classified as simple (Group 1), where separation from MV occurs within 24 hours of initiating the process; difficult (Group 2), where liberation occurs between 24 hours and 7 days after starting weaning; prolonged (Group 3) where separation is not completed within one week of starting the weaning, and the patient either successfully weans (3a) or never weans off MV (3b); no weaning (Group 0), which includes patients who never attempted liberation from MV.[1]

Multicenter and international studies[1,2] report a prevalence of prolonged weaning of 8.7-9.6%, associated with a mortality rate of 29.8% in this subgroup of patients. An article published in an European journal found a prevalence of prolonged weaning of 15%.[3] In Argentina, the prevalence of prolonged weaning was 14.9%, with a mortality rate of 36.1% in this group. Prolonged weaning is therefore associated with worse patient outcomes, including increased mortality, longer stays in the Intensive Care Unit (ICU), and extended hospital stays. Furthermore, alongside age, the duration of MV is the strongest predictor of functionality one year after hospital discharge.[4]

One of the reasons why patients fail to wean is diaphragmatic dysfunction or weakness.[5] This condition is diagnosed when the maximal diaphragmatic pressure (Pdi max), measured through esophageal and gastric manometry, is less than 60 cmH_2O.[6] Approximately 63% to 80% of patients exhibit diaphragmatic weakness at the time of weaning, and 80% of patients undergoing prolonged weaning experience this dysfunction.[7]

Diaphragmatic weakness is not always associated with Intensive Care Unit-Acquired Weakness (ICUAW), which is diagnosed by evaluating the strength of the upper and lower limbs. During weaning, diaphragmatic weakness is twice as common as weakness in limb muscles, making these two conditions completely different entities.[8]

For this reason, inspiratory muscle training (IMT) has been proposed as a treatment strategy for patients with diaphragmatic weakness associated with prolonged weaning. IMT focuses on strengthening the diaphragm and accessory inspiratory muscles to improve muscle strength and endurance.[9]

Respiratory muscles respond to the same training principles as other skeletal muscles: overload, specificity, and reversibility. These principles are important in designing IMT protocols, which include threshold loading, resistive loading, and full-body mobilization.[9]

To achieve a training response, it is necessary to overload the muscle fibers with a stimulus of intensity and duration that exceeds the training threshold. Additionally, specific loading leads to specific training responses (principle of specificity), and the physiological adaptations achieved through training are reversible, meaning they are lost during periods of inactivity.[10]

A survey among French physiotherapists revealed that 83% considered controlled diaphragmatic breathing (without resistance) as a form of inspiratory muscle training, while only 16% measured the strength of the inspiratory muscles.[11]

The primary objective of this narrative review is to present the available evidence on the implementation of IMT in mechanically ventilated patients, the devices used, the existing application methods, and the impact on weaning variables, respiratory muscle strength, and quality of life.

MATERIALS AND METHODS

A bibliographic search was conducted in the database of PubMed, Virtual Health Library (VHL), and Cochrane for articles published up to December 2023 using the following MeSH terms and combined keywords: "Ventilator Weaning" OR "Respirator Weaning" OR "Mechanical Ventilator Weaning" AND "Respiratory Muscle Training" OR "Respiratory Muscle" OR "Ventilatory Muscles." After applying filters (full text, age over 18 years, studies in humans), 22 articles were selected from 1,088 results. The selection included multicenter studies, observational studies, randomized controlled trials, and systematic reviews. The search was manually supplemented by reviewing the references of the selected articles, resulting in a total of 27 studies. Figure 1.

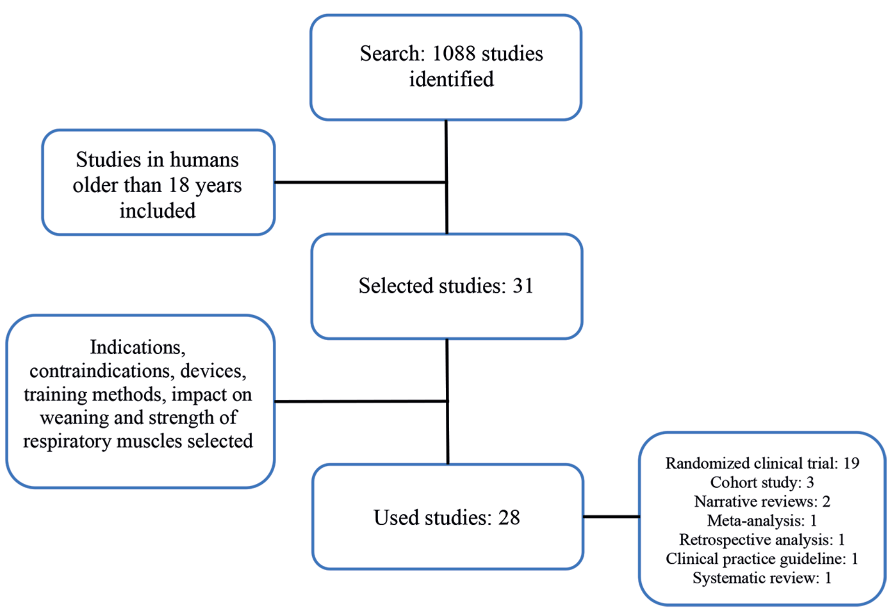

Figure 1. Flow diagram

DEVELOPMENT

Indications and contraindications of IMT

There are several factors to consider when determining if IMT is appropriate for a patient in the ICU. Since the training requires active participation from the patients, their level of alertness and cooperation is essential. Patients must be sufficiently awake to understand the purpose of intermittent loading and perceive it as a temporary training stimulus. Therefore, minimizing sedation is a crucial component of the multidisciplinary approach of IMT in the ICU.[12]

Training is feasible in patients with a tracheostomy or endotracheal tube. Because it relies on threshold loads, IMT requires disconnection from mechanical ventilation. Consequently, patients should not depend on high levels of positive end-expiratory pressure (PEEP), as disconnection could lead to derecruitment and atelectasis. However, for clinically stable patients with PEEP levels < 10 cmH_2O and FiO_2 < 0.60, IMT does not result in changes to clinical parameters. Additionally, hemodynamic parameters must be stable at the time of training.[12] IMT can be beneficial in the process of weaning from mechanical ventilation for certain patients. It is particularly useful for those who, after 7 days of connection have not succeeded with standard methods such as progressive T-tube trials. Furthermore, it may be effective in patients with Pimax (maximal inspiratory pressure) values greater than -30 cmH_2O, as this criterion is considered an indicator of successful weaning.[13]

There are several conditions in which IMT wouldn't be appropriate, such as patients in the acute phase, experiencing severe pain, dyspnea, or those for whom palliative care has been proposed.[12] **Table 1.**

TABLE 1. Inclusion and exclusion criteria for an IMT program

Inclusion and Exclusion Criteria for an Imt Program
Indications
• Alert and cooperative • PEEP < 10 cmH_2O • FiO_2 < 0.60 • Hemodynamically stable • Pimax greater than -30 cmH_2O
Relative contraindications
• Acute phase of the condition • Deep sedation • Severe pain • Dyspnea • Palliative care

PEEP (positive end-expiratory pressure), FiO_2 (fraction of inspired oxygen), Pimax (maximal inspiratory pressure)

IMT devices

There is a wide range of techniques used for respiratory muscle training, including external resistive loading devices, external threshold pressure loading devices, adjustments to the trigger sensitivity of mechanical ventilators, and training with abdominal weights.[14-16]

First, resistive loading devices involve placing a resistor in the patient's airway, which increases airflow resistance during inspiration. This increased resistance requires the respiratory muscles to generate greater pressure to achieve the necessary airflow. Therefore, the pressure generated depends directly on the inspiratory flow that the patient can achieve.[17]

Secondly, threshold loading devices use a valve in the airway, set to a specific pressure level. To open this valve and allow airflow, the patient's respiratory muscles must generate the required pressure. Unlike resistive loading devices, the effect of training with threshold loading devices is independent of the patient's individual respiratory mechanics and respiratory drive, simplifying standardization.[9,11,17]

Trigger sensitivity is determined by the pressure threshold in the circuit that the patient must reduce to open the inspiratory valve and achieve inspiratory gas flow.[18]

On the other hand, training with abdominal weights increases intra-abdominal pressure, which stimulates diaphragm contraction, thereby strengthening the respiratory muscles.

Finally, there is no evidence to support the idea that deep breathing exercises without resistance result in significant improvements in respiratory muscle strength or enhance the weaning process in ICU patients.[11]

Training methods

Inspiratory muscle training targets the diaphragm and accessory inspiratory muscles to improve muscle strength and endurance. Two treatment approaches can be distinguished: strength training program with moderate to high loads and low repetitions,[19] or an endurance training method which uses low-intensity loads with many repetitions sustained over a set work period.[20] Although respiratory muscles are primarily endurance muscles, with the diaphragm composed of 80% fatigue-resistant fibers (55% type I and 25% type IIa),[21] a recent systematic review that separately analyzed strength and endurance training regimens found that both approaches benefit respiratory muscle training compared to control groups.[9]

Based on the experience of some authors,[11] a strength training regimen is more feasible for ICU patients. This is partly because it involves less time of disconnection from mechanical ventilation, reducing alveolar derecruitment. Additionally, it requires less time of collaboration from the patient, who is often affected by fatigue, lack of attention, delirium, and other factors.[11]

The duration of respiratory muscle training varies significantly across studies. Ibrahiem et al[22] propose conducting training twice daily for three days. Conversely, in the study by Bissett et al,[23] training continued until patients were successfully weaned from mechanical ventilation.

The various training approaches are distinguished in Table 2.

Impact on mechanical ventilation weaning

The findings from studies regarding the impact on the duration of weaning from mechanical ventilation are contradictory. Four studies[15, 24-26] examining various forms of training (Threshold, trigger sensitivity, and Powerbreath) don't show significant differences in weaning time. In contrast, five other studies[27, 28, 30–32] reported a reduction in weaning time, with two of them[31, 32] showing a significant decrease when the Threshold device was implemented. This aligns with the review conducted by Vorona et al[9], which associated IMT with a significant reduction in weaning duration, even when studies with a high risk of bias were excluded (3.2 days; 95% CI 0.6-5.8).

Regarding the studies by Sandoval Moreno et al[24] and Caruso et al,[15] the lack of significant differences in weaning times between groups can be explained by the short duration of IMT in these studies. This is because training began within 48 to 72 hours of initiating MV, respectively, and patients were extubated early, suggesting an absence of respiratory muscle dysfunction associated with MV.[24] In a randomized clinical trial (RCT),[15] IMT was performed by reducing the sensitivity of the ventilator's trigger, which provided initial resistance to opening the ventilator valve. On the other hand, IMT with the Threshold device offers resistance throughout the entire inspiratory phase, as reported by Cader et al.[27]

Four studies[9,14,16,26] examined the impact of IMT on the duration of mechanical ventilation, and only the study by Elbouhy et al[14] reported a significant reduction in MV duration (11.67 days ±1.95 vs. 14.12 days ±1.73). In a study conducted in England, patients were divided into two intervention groups: one subjected to abdominal weights and the other combining abdominal weights with the use of a cough machine. This device applies positive inspiratory pressure, which instantly converts into high-flow negative expiratory pressure, increasing peak cough flow and effectively clearing respiratory tract secretions.[16] While a reduction in MV days was observed, statistical significance was not achieved. However, the study highlighted limitations, including a lack of scientific rigor due to differences in training loads and durations, as well as a small sample size. Although the review by Vorona et al[9] initially associated IMT with a reduction in MV duration, by excluding studies with a high risk of bias, this difference was non-significant, consistent with the findings of Shimizu et al.[26]

Regarding weaning success, two RCTs implementing the Threshold device[19,31] and one adjusting trigger sensitivity for training[14] reported significant differences in the experimental group. Similarly, the study by Bissett et al[33] reported a lower rate of orotracheal reintubation in this group (45% vs. 76%; OR 0.603).

In one study[34] including patients with cervical spinal cord injuries who underwent a rehabilitation program including IMT, 70% of the patients were successfully weaned and decannulated, except for three patients with spinal cord injuries category A according to the ASIA (American Spinal Injury Association) at the C1 level. Two other studies reported no significant differences in weaning success: Sandoval Moreno et al[24] found no differences in weaning failure. Hung TY et al[16] observed no differences in reintubation rates.

Effects on respiratory muscle strength

The effects of IMT on respiratory muscle strength were investigated in eighteen studies.[9,15-19,22,24-32,35-37] Four studies[17,22,30,35] demonstrated that this training correlated with a significant increase in maximal inspiratory pressure (Pimax) from the beginning in patients undergoing training compared to the control group. Three studies[24,26,29] reported

TABLE 2. Methods for respiratory muscle training

	Type of study	Device	Load	Repetitions/ series	Rest between each series	Stimuli
Bissett 2023[32]	Randomized clinical trial	Threshold IMT	50% Pimax	5 series of 6 repetitions		Once daily, 5 days a week
Khodabandeloo 2023[30]	Randomized clinical trial	Threshold IMT	Initially 50% of Pimax	5 series of 6 repetitions	1 minute between series with MV support	Daily
Ratti 2022[24]	Randomized clinical trial	Electronic IMT	30% Pimax			
Hung TY 2022[16]	Randomized clinical trial	Abdominal weights (sand bag)	Initial weight: 1 to 2 kg.	30 minutes		2 times a day, 5 days a week
Bisset 2019[13]	Clinical practice guideline	Threshold IMT	50% Pimax	5 series of 6 repetitions		Once daily
Hoffman 2018[40]	Randomized clinical trial protocol	Electronic IMT	Highest tolerable Between 30% and 50% Pimax	4 series of 6 to 10 repetitions	2 minutes	Once daily
Tonella 2017[27]	Randomized clinical trial	Electronic IMT	30% Pimax	3 series of 10 repetitions	1 minute	2 times a day
Sandoval Moreno 2017[23]	Randomized clinical trial	Threshold IMT	50% Pimax	3 series, 6 to 10 repetitions	2 minutes	2 times a day, every day
Bissett 2016[34]	Randomized clinical trial	Threshold IMT	50% Pimax	5 series of 6 repetitions	1 minute	Once daily
Gundogdu 2016[33]	Prospective cohort	Threshold IMT	Intensity of 2 on a 0-4 inspiratory effort scale	10 repetitions		3 times a day, 5 days a week
Ibrahiem 2014[21]	Randomized clinical trial	Threshold IMT	30% Pimax	6 series, 5 to 6 repetitions	Connection to MV between series as needed	2 times a day for 3 days
Pascotini 2014[38]	Randomized clinical trial	Threshold IMT	20% Pimax	3 series, 10 re-petitions	2 minutes	1 time a day, every day
Shimizu 2014[25]	Prospective cohort	Threshold IMT	50% Pimax	3 series, 10 re-petitions	1 minute with connection to MV	Two times a day
Dixit 2014[31]	Randomized clinical trial	Threshold IMT	30% Pimax initially, up to effort intensity of 6-8 on a 10-point RPE scale	5 series, 6 repetitions	1 minute of rest between series with MV support.	Two times a day, 7 days a week
Saad IAB 2014[36]	Randomized clinical trial	Electronic IMT	30% Pimax	3 series, 10 re-petitions	1 minute between series	
Kellerman 2014[41]	Prospective cohort	Threshold IMT	Highest intensity allowing valve opening	4 series, 6 to 10 repetitions	2 to 3 minutes	Daily
Elbouhy 2014[14]	Randomized clinical trial	Trigger sensitivity	Trigger sensitivity at 20% Pimax	5 to 30 minutes		2 times a day, 5 days a week
Condessa 2013[29]	Randomized clinical trial	Threshold IMT	40% Pimax	5 series, 10 repetitions		2 times a day, every day
Lee CY 2012[35]	Randomized clinical trial	Abdominal weights (sand bag)	10% of body weight	30 minutes a day		5 days a week
Hollebeke 2012[28]	Randomized clinical trial	Electronic IMT	30% Pimax	4 series, 8 repetitions	2 minutes	
Martin 2011[18]	Randomized clinical trial	Threshold PEP	Maximum tolerable pressure	4 series, 6 to 10 repetitions		Once daily, 5 days a week
Cader 2010[26]	Randomized clinical trial	Threshold IMT	30% Pimax	5 minutes		2 times a day, every day
Caruso 2005[15]	Randomized clinical trial	Trigger sensitivity	20% Pimax	5 to 30 minutes		2 times a day

Inspiratory muscle training (IMT), Pimax (maximal inspiratory pressure), MV (mechanical ventilation), RPE (rate of perceived exertion) differences in muscle strength that did not reach statistical significance.

Several studies[19,22,24,27,28,35-37] showed a significant improvement in the final Pimax compared to baseline exclusively in patients who received daily IMT with a threshold load. In contrast, four studies[25,26,29,31] observed a significant increase in Pimax in both the experimental and control groups.

Dixit et al[32] evaluated 30 patients with prolonged MV and divided them into two groups. Group A underwent conventional physiotherapy. Group B received conventional physiotherapy combined with IMT using a Threshold device. As a result, a Pimax increase was observed in both study groups, but it was significantly greater in Group B compared to Group A (-43.87 ± 8.01 vs. -35.68 ± 4.48; p = 0.0009).

In a 2022 study[16], thirty patients with similar clinical and demographic characteristics were randomly assigned to two groups. One group underwent IMT with abdominal weights. The other combined abdominal weights with the use of a cough machine. Results revealed a significant improvement in both Pimax and maximal expiratory pressure (Pemax) in both groups.

In a systematic review,[9] the Pimax increased by 40% in patients exposed to IMT, compared to an 18% increase in the control group. Differences were also observed in the Pemax, which increased by 63% in the IMT group versus 17% in the control group. The Pimax tended to increase with strength training compared to endurance training and when using the Threshold device. But the difference between subgroups was small and did not reach statistical significance. Figure 2.

Impact on pulmonary function

Respiratory muscle training can generate changes in the strength (as reflected in the Pimax and Pemax), and it can also lead to changes in pulmonary function. Several studies have described variations in parameters such as the rapid shallow breathing index, tidal volume, respiratory rate, and inspiratory flow, among others.

Some studies[16,30,31,36] demonstrated improvements in the rapid shallow breathing index after patients participated in a respiratory muscle training program. Conversely, Tonella et al[28] reported no significant changes in this index. In a RCT[27] where the IMT was performed with a threshold-loading device versus standard care, an increase was observed in the mentioned index in both study groups. However, this increase was smaller in the intervention group (mean difference -8.3; 95% CI -13.7 to -2.9). Despite the observed increase, both groups remained below the cutoff value proposed as predictor of successful weaning, which

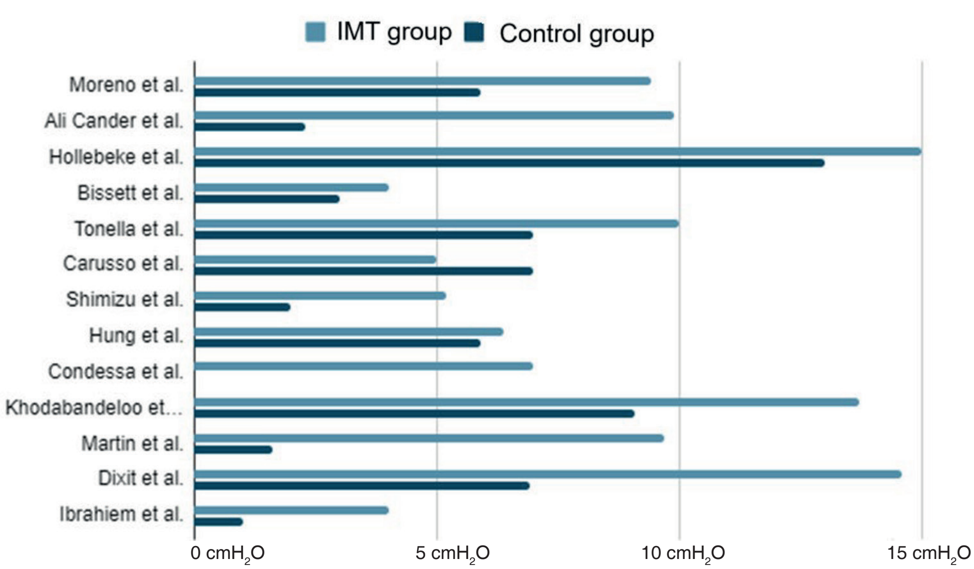

Figure 2. Differences between the initial and final Pimax in both groups

is less than 105 breaths/min/L and corresponds to breaths per minute divided by the tidal volume (TV) in liters.[38]

Changes in TV were considered in some studies. In the study by Condessa et al[30], the TV increased in the intervention group undergoing IMT, while a decline was observed in the control group (mean difference 72; 95% CI 17 to 128). This improvement in TV could explain the improvement in the rapid shallow breathing index in the intervention group. Similar results were found in three articles[16,29,36] which reported increased volumes following respiratory muscle training.

Hung TY et al[16] observed a significant improvement in vital capacity, Pimax, Pemax, and peak cough flow with respect to baseline values in the experimental group, compared to the control group. In the study of Lee CY et al,[36] an improvement was observed in respiratory rate, minute volume, and breathing pattern after IMT. Hollebeke et al[29] documented increases in inspiratory flow and in the oxygenation of respiratory muscles following an IMT program, along with a significant reduction in the work of breathing (WOB) in this group.

Pascotini et al[39] found that patients treated with conventional physiotherapy experienced an increase in respiratory rate. In contrast, patients who received IMT with the Threshold device in addition to conventional therapy showed a reduction in respiratory rate.

Impact on survival rate and quality of life

A 2017 study[40] reported that patients undergoing IMT had a higher survival rate 30 days post-intervention compared to the control group, of 79% and 44%, respectively, and those values turned out to be statistically significant.

Bisset et al[35] assessed quality of life using the EQ-5D and SF-36 scales. Both measures showed statistically significant improvements from baseline in the IMT group only. The difference regarding the EQ-5D scores between groups was greater in the IMT group (mean difference 12; 95% CI 1–23; $p = 0.034$). No significant differences were observed in SF-36 scores between groups, although point estimates suggested potential benefits. While the results did not reach statistical significance, data suggest a trend towards improved quality of life in relation to health, defined as the well-being level derived from an assessment made by an individual of various life domains, considering the impact of their health status,[43] which could indicate a potential benefit of the treatment. On the other hand, a significant increase in mortality was reported in the IMT group, though none of the deaths were linked to respiratory complications from IMT. So, this increased mortality may be attributed to patient comorbidities and the severity of their condition upon hospital admission.

CONCLUSION

Despite the variability of studies regarding training methods and the optimal load, respiratory muscle training in adult patients under MV can result in improved respiratory muscle strength, reduce the duration of mechanical ventilation in specific patients, and improve quality of life. Given the fact that the weakness of these muscles has a clear impact in the outcomes both in and out of the ICU, incorporating personalized, targeted respiratory muscle training into conventional respiratory therapy could help maximize patient recovery.

Conflict of interest

Authors have no conflicts of interest to declare..

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